Final Technical Memorandum
Milltown Reservoir Dry Removal Scour Evaluation

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amsl	above mean seal level
ARAR	Applicable or Relevant and Appropriate Requirements
AWQC	Ambient Water Quality Criteria
BFR	Blackfoot River
BOD	Biological Oxygen Demand
BR	Bitterroot River
cy	cubic yards
CFR	Clark Fork River
CFROU	Clark Fork River Operable Unit
EPA	Environmental Protection Agency
mcy	million cubic yards
MDEQ	Montana Department of Environmental Quality
MRSOU	Milltown Reservoir Sediments Operable Unit
RD/RA	Remedial Design/Remedial Action
SAA	Sediment Accumulation Area
SOW	Statement of Work
TRV	Toxicity Reference Value
TSS	Total Suspended Solids
USGS	United States Geological Society
WY	Water Year

1 Introduction

1.1 Site Location and Description

The Milltown Reservoir was created in 1907 by the construction of the Milltown Dam at the confluence of the Clark Fork River (CFR) and the Blackfoot River (BFR). The Milltown Dam is located approximately 7 miles east of Missoula, Montana and is adjacent to the small, unincorporated communities of Milltown and Bonner. The historic mining communities of Butte and Anaconda are upstream. During the past century, mine wastes and natural sediment materials have washed downstream, creating some 7 million cubic yards (mcy) of sediment accumulation behind the Milltown Dam. Figure 1-1 provides an air photo site map of the reservoir sediments area and shows the five key Sediment Accumulation Areas (SAA) behind the Milltown Dam. Only a portion of the reservoir sediments area, occupying much of SAA I (see hatched area on Figure 1-1), has been identified as the primary source of the groundwater arsenic plume associated with the Milltown Reservoir Sediments Operable Unit (MRSOU).

The MRSOU includes the Milltown Reservoir and the adjacent areas of arsenic-impacted groundwater and the upland disposal facility. The reservoir boundary is defined as the area inundated by a maximum pool elevation of 3,263.5 (based on local dam vertical datum) feet above mean sea level (amsl). The maximum pool elevation is based on the reservoir operation as controlled by NorthWestern Energy's Milltown Dam. The reservoir area (including both deposited sediment and open water areas) covers approximately 540 acres and extends a distance of approximately 2 miles southeast of the dam up the CFR valley.

1.2 Review of Remediation Options

The Cleanup Proposal for the MRSOU (EPA, 2003a) identified a preferred alternative that involved removal of SAA I sediments using hydraulic dredging under a full reservoir pool approach. As an alternative to the Cleanup Proposal's wet sediment removal approach, Envirocon has proposed removing the SAA I sediments in the dry using a reservoir drawdown/sediment preloading approach. Dry removal approach specifics are detailed in the preliminary Remedial Design/Remedial Action (RD/RA) Statement of Work (Atlantic Richfield, 2003) but generally involve dewatering the sediments prior to removal using either reservoir drawdown with the dam in place or early removal of the spillway/radial gate section of the dam. Table 1-1 provides a comparison of the advantages and disadvantages of the proposed Environmental Protection Agency (EPA) original Cleanup Proposal and Envirocon remediation approaches. As identified on Table 1-1, the advantages provided by Envirocon's dry removal mechanical excavation approach greatly outweigh the potential disadvantages. However, it was recognized that if the reservoir is drawn down or the dam is breached prior to, or during, the SAA I sediment excavation process, some degree of scour of the sediments in the existing reservoir channels along with an associated increase in downstream suspended sediments and metals loads would be expected during construction.

The purpose of this technical memorandum is to quantify and analyze the impacts of reservoir drawdown or early dam removal on reservoir sediment scour during construction by modeling various drawdown and dam breach options under different flow and sediment management operational conditions. Predicted scour depths and volumes and the total mass of sediment released from the reservoir were determined for each option evaluated. In addition, total suspended solids (TSS) and dissolved metals concentrations leaving the dam were also estimated and compared to applicable standards and risk based criteria.

1.3 Applicable Compliance Criteria

Applicable or relevant and appropriate requirements (ARARs) are the basis for the preliminary remediation goals EPA developed for the MRSOU. Specific ARARs for surface water are provided in Table 1-2. Overall, the proposed remedy is predicted to comply with most ARARs for this Site. In certain circumstances, an ARAR may be waived at a site. A waiver must be invoked for each ARAR that will be exceeded or not attained.

For surface water, the proposed remedy for the MRSOU is not expected to achieve compliance at all times with the State's WQB-7 standards because of continued contaminant loading originating upstream of the reservoir which is outside the scope of this operable unit cleanup. The EPA's Cleanup Proposal for the Clark Fork River Operable Unit (CFROU) evaluated the ability to reduce contaminant loads and concluded that is likely to be technically impracticable to consistently achieve surface water standards in the CFR upstream of the MRSOU under the proposed CFROU remedial action. As discussed in the Statement of Work (SOW), it is anticipated that a technical impracticability waiver of surface water ARARs implemented for the CFROU will be extended through, and downstream of, the MRSOU. State (WQB-7) standards would be waived during construction, and temporary standards would be put in place of these standards. The proposed remedy does include removal of the most contaminated reservoir sediments, and this action will reduce the contribution of contaminants of concern to the CFR that originates from the reservoir area under certain conditions. EPA anticipated in their original Cleanup Proposal that the MRSOU Proposed Action will likely eliminate the potential for negative impacts on aquatic life during ice scour events.

Predicted water quality results of the modeling will be compared with the Proposed "Temporary Construction-related Water Quality Standards" identified in EPA's Cleanup Proposal for the MRSOU. Table 1-3 lists temporary surface water standards to be used during the construction implementation portion of the project. These temporary standards were established by EPA and the Montana Department of Environmental Quality (MDEQ) to protect human health and prevent acute impacts to the downstream fishery and bull trout with the proposed point of compliance set 2.8 miles downstream of Milltown Dam at the current United States Geological Society (USGS) "CFR above

Missoula" sampling station. Water quality at this station is assumed to be approximately the same as that directly below the dam since the CFR through this stretch contains no additional flow inputs or significant sediment sources, making this station appropriate for water quality monitoring of remedial construction activities at Milltown Reservoir. This assumption is considered to be conservative given that it ignores the potential for a portion of the sediments and metals scoured from the reservoir to attenuate in the intervening 2.7 miles between the dam and the water quality compliance point.

The standard for dissolved copper compliance is 25 *u*g/L and is based on a value equal to 80 percent of the hardness-dependant acute trout Toxicity Reference Value (TRV) for dissolved copper in the CFR. Standards for other dissolved metals are based on ambient water quality criteria or, in the case of the long-term standards for arsenic (i.e., 10 *u*g/L) and lead, drinking water standards.

Based on the available water quality sample results data base for the site and the results of previous modeling runs, compliance with water quality standards for constituents other than TSS, dissolved copper and dissolved arsenic were not considered to be of potential concern. Therefore, the comparison to Temporary Construction-related Water Quality Standards focuses on TSS, dissolved copper, and dissolved arsenic concentrations.

2 Stream Morphology and Sediment Distribution/Properties

2.1 Historic Changes in Channel Planform and Cross-section

The confluence of the BFR and CFR has historically been a hydraulic choke point. This in the past has slowed the velocities in the approach to the confluence, causing the CFR to transition from a meandering planform to more of a braided planform (indicating a depositional area). Planform channel locations of the CFR upstream of the Milltown site are compared in Figure 2-1 for years 1893, 1903, 1937, 1966, and current conditions, using historical survey data and aerial photography. Milltown dam was completed in 1907. As can be seen in planform, the channel moved significantly between 1900 and 1966, but has been relatively stable since 1966. It should also be noted that the CFR had a multi-thread channel in the upstream part of the reservoir and upstream of that, even before the dam was completed. It should be expected to adjust to a similar planform in the upstream reservoir following dam removal and will continue to maintain that pattern further upstream. A single thread meandering channel would not be expected unless it will be a structurally maintained channel.

Milltown Dam has caused a significant amount of deposition of sediment in the reservoir and river reaches just upstream of the reservoir. However, a comparison of historical changes in cross section and thalweg profile of the CFR between Turah and Milltown suggests that in the past 20 to 25 years, this reach has been generally flowing under dynamic equilibrium conditions. In other words, there has been no appreciable net scour or deposition anywhere in the reach over that time period. Channel profiles are presented in Figure 2-2, based upon cross sectional surveys conducted in 1981, 1990, 1996, and 1997.

Cross sections, particularly in the reservoir portion of the reach have remained fairly consistent in shape, with only local changes in bed elevation. A typical example of the geomorphic evolution of the reach through the reservoir is cross section “F”, shown in Figure 2-3a. It appears that since 1981, the main channel is tending towards a leftward migration, but the main channel flow area has remained the same, indicating that a dynamic equilibrium has been achieved.

Upstream of Milltown Reservoir, the river is more braided, and the main channel has migrated quite a bit. Although the channel has moved around laterally, the flow areas of the primary and secondary channels haven’t changed significantly. This is particularly evident in cross section “O” shown in Figure 2-3b. Additional cross sections were compared and are available on request.

Further evidence of the dynamic equilibrium nature of the CFR above Milltown Dam is the little change in thalweg elevation throughout the reach over the past 20 years (Figure 2-2).

2.2 Conceptual Model of SAA III Sediments

As noted in Section 1.1, the sediments that have accumulated in the reservoir since the dam was constructed have been divided into five SAAs. Of greatest importance to the scour evaluation are the sediments located in SAA III, the existing CFR and BFR channels between the dam and Duck Bridge (for the CFR) and the I-90 overpass (for the BFR). Core sampling performed for the remedial investigation (RI) had identified these SAA III sediments as generally being thinner, coarser-grained and having lower metals concentrations than off-channel sediments in adjacent SAAs. However, subsequent to the RI, additional core sampling performed by EPA in 2002 and Envirocon in 2003 identified that the portion of the SAA III sediments located in the CFR limb immediately upstream of the dam had thicker sediments (up to 21 feet thick). The surficial sediments in this area were similar in grain size and metals concentration to the upstream portion of the CFR channel in SAA III. However the deeper sediments (at depths below 2’) were finer-grained and had generally higher metals concentrations than the rest of the SAA III sediments. Appendix A provides core logs detailing the SAA III lithology as determined by RI and subsequent investigations. Figure A-1 shows the horizontal distribution of the cores. Generally, the core logs show the SAA III bed to be made up of thick layers of finer-grained-sized sediment material, predominantly silty and clayey sands, overlying gravel and cobble alluvium which in turn overlies argillite bedrock. Figure 2-4 graphically summarizes the range of grain size distributions determined by EPA in 2002 for the deeper sediment material in the CFR channel portion of SAA III. Figure 2-4 also identifies the location of the higher metals concentration sediments in SAA III and provides a summary of total copper and arsenic concentrations for the EPA's SAA III cores collected both within and outside the higher metals concentration area.

3 Historic Surface Water Quality Data Summary

To provide context to the modeled results of predicted TSS concentrations during the potential remedial action scenarios, this section summarizes previous water quality monitoring for the site during normal as well as reservoir drawdown conditions. In addition, the methodologies and equations developed in these previous studies to correlate between various water quality parameters are also briefly discussed to identify the basis used in this evaluation for estimating other water quality parameters from modeled TSS concentration results.

3.1 During Full Pool Reservoir Conditions

Figures 3-1 through 3-3 show water column TSS, arsenic and copper concentrations measured at the CFR above Missoula station over time, respectively. USGS began regularly monitoring at the CFR above Missoula station in December of 1989. Montana Power Company data was used to supplement the historic USGS data set in years prior to 1989. Further data for the Missoula County Health Department grab samples collected during the 1996 ice scour event were also included in the figures. The effect of seasonal flows on TSS, arsenic and copper concentrations are shown in these figures by the higher concentrations observed during spring high flows. The largest peaks over the period of record occur during the 1996 ice scour and 1997 high flow events. Drawdowns also affect concentrations but only the 2002 Drawdown of 10 feet below full pool increased concentrations significantly. Dissolved metals concentrations are much less variable than TSS and total metals concentrations.

The specific impact of the reservoir on downstream concentrations can be evaluated by comparing contemporaneous upstream and downstream loading. The difference in the upstream and downstream loads converted to an “incremental” downstream concentration identify whether the reservoir is acting as a net sink or source at the time. Incremental concentrations due to the reservoir for various constituents plotted against time (Figures 3-4 through 3-6, respectively) are generally negative showing that the reservoir is more often a net sink than a source. The exception to this is typically during high flows and drawdowns when the reservoir can be a significant net source of TSS and total (although typically not dissolved) metals. Incremental concentrations during the 1996 ice scour event could not be calculated because contemporaneous sampling did not occur at the BFR near Bonner station during that particular event.

According to the USGS, normal sediment discharge through the reservoir between 1991 and 1997 was approximately 148,000 tons per year based on measurements made at the CFR above Missoula gaging station (USGS, 1998). Table 3-1 provides typical downstream loads at the CFR above Missoula station. Based on measurements at the CFR Turah and BFR near Bonner stations, approximately 142,000 tons per year of suspended sediment were transported into the reservoir suggesting there was on average a net scour of 6,000 tons per year of sediment from the reservoir over the 1991-1997 timeframe. Approximately 762,000 tons of sediment was discharged from the reservoir during the high flow years of 1996 and 1997 (i.e., 317,000 tons and 445,000 respectively). An estimated 655,000 tons of sediment was transported into the reservoir during this two-year period suggesting a net scour of 107,000 tons. The period from 1991 through 1995 indicated a reduced volume of sediment discharge through the reservoir with an estimated average of 55,485 tons per year measured at the CFR above Missoula gage and a net storage in the reservoir of about 13,000 tons of sediment per year. According to the USGS, the 1991–1995 period is more heavily weighted to lower flow rates and therefore the 1991-1997 period is considered to be more representative of long-term sediment transport conditions at Milltown Reservoir.

On average, the BFR contributes about 45 percent of the incoming sediment load to the reservoir and the CFR contributes the remaining 55 percent. The reservoir is currently filled to capacity with sediment and the USGS believes that reservoir storage is in long-term equilibrium with incoming sediments.

Metal concentrations downstream of Milltown Reservoir during normal operations are largely a function of influent water quality from upstream reaches of the CFR (ARCO, 1995). Table 3-2 provides the average (from 1991-1999) total and dissolved copper concentrations at the two stations upstream and the one station downstream of the reservoir. Comparison of flow-weighted concentrations above the dam with measured concentrations below the dam shows strong correlation and does not show any statistically significant differences.

3.2 During Drawdown Conditions

Dam operations can influence downstream water quality by releasing stored sediments in the reservoir. As shown on Figures 3-1 through 3-3, elevated downstream TSS and metals concentrations have been historically associated with drawdown periods particularly when the drawdown occurs rapidly (as in the case of the 1996 ice scour event) or is of large magnitude. A rapid drawdown in July 1980 resulted in a turbidity (which is typically closely correlated to TSS) increase 25 times that of the typical level (Land & Water Consulting, 1999). Slow drawdown occurring after the annual hydrograph peak is typically able to maintain the increase in downstream turbidity levels to within 4-5 fold of background. During the 2002 drawdown, there was a significant 10-foot drawdown, which increased downstream TSS concentrations by approximately 40 times to a maximum of 162 mg/L as seen in Figure 3-7. However, the 2003 drawdown had a 5.5-foot drawdown with little effect on downstream TSS concentrations (Figure 3-8).

4 Sediment Transport Modeling Upstream of Dam

4.1 Dam Removal Scour Predictive Modeling Capabilities and Precedents

A number of dams have been removed in the last 25 years, or are in the process of removal today. The largest being considered in the U.S. today are the Elwha River Dams that form Lake Mills and Lake Aldwell on the Olympic Peninsula in Washington. It is estimated that 4 million mcy of fine sand and 1.5 mcy of coarse sediment will be eroded from Lake Mills, and that 1.5 mcy of fine sand and 1 mcy of coarse sediment will be eroded from Lake Aldwell during the three-year dam removal. One of the earlier dam removals was the Fort Edwards Dam on the Hudson River in 1975 where 850,000 cubic yards (cy) of material eroded the first year of dam removal activities. The Washington Water Power Dam on the Clearwater River in Idaho was removed in 1977. 387,000 cy were eroded over a 10-year period following that dam removal. A number of dams have been removed in the United States since that time though most of them have been small (Aspen Institute, 2002; Dam Removal Research, The Heinz Center, October 2002).

Numerical sediment transport models have been used to predict the fate and transport of sediment following dam removal since the Fort Edwards Dam and the Washington Water Power Dam removals in the mid-1970s. The numerical model chosen in those two cases was the Corps of Engineers HEC-6. It was also used to model the Elwha River between Lake Mills and Lake Aldwell and for downstream reaches.

Consistent with these dam removal precedents, the computational model "HEC-6, Scour and Deposition in Rivers and Reservoirs" was used to analyze the sediment transport resulting from the removal of Milltown Dam. HEC-6 is a one dimensional movable boundary open channel flow numerical model designed to simulate and predict changes in river profiles resulting from scour and/or deposition over moderate time periods" (HEC-6, 1993). Because it is a one-dimensional model, HEC-6 averages hydraulic and sediment properties over each cross-section. HEC-6 has been used extensively for sedimentation studies for over 25 years. Its applications have proven to be far reaching and it has indeed been used successfully in the analysis of dam removal effects on sediment transport.

HEC-6 is able to handle the full range of sediment particle sizes and allows for the variance of sediment gradation from one cross section to the next. It has multiple sediment transport functions available and can be effectively used for long-term simulations. Furthermore, it is accessible to the public and relatively easy to run.

Sediment transport due to the removal of Milltown Dam is a good candidate for analysis by HEC-6. The reservoir is fairly one-dimensional in nature, being that the dam is "run of river", and as a result has more riverine characteristics than most reservoirs. Analysis of the cross sections in the reservoir indicate the presence of a pronounced main channel, which further supports the use of HEC-6. Having the main channel will ensure that the primary currents remain dominant in the model simulation, allowing the secondary currents to be ignored (critical for one-dimensional modeling). Braided rivers and streams, such as the braided reach upstream of the reservoir, are typically not suited for a one-dimensional model such as HEC-6. However, throughout most of the braided reach in the CFR there appears to be a dominant channel in which one can expect most of the sediment movement to occur. Under this Scenario, the final bed elevations may not be accurate, however, by properly defining ineffective flow areas and moveable bed zones, the amount of sediment scoured and the resulting suspended sediment concentrations can be fairly accurate.

The sudden removal of a dam can initiate a dynamic response such as head cutting. HEC-6 does not currently have the capability to model head cutting and it would be a limitation for this study if a sudden or near-instantaneous dam removal was expected. The dam removal Scenario modeled by HEC-6 for Milltown Dam assumes a gradual reservoir drawdown and dam removal over a period of months. This is considered gradual enough that the bed level degradation in the reservoir will not be surpassed by the drawdown of the water level, minimizing the chance of head cutting. In addition, the cross section spacing is close enough (approximately one river width or less) in the reservoir that the model should be able to approximate the sudden energy changes associated with a drawdown event. Finally, small time steps are critical in properly modeling the sediment transport processes associated with dam removal. Time steps used here are normally half-day intervals, but were shortened during the removal stages to approximately $1/10^{th}$ day or less intervals. For a snow melt system mean daily flows are normally sufficiently short to adequately represent the stream hydrology and the shorter time steps during the phased removal were short enough to eliminate numerical instabilities. Numerical instabilities can be a problem if a dam is quickly or instantaneously removed in which case extremely small distances between cross sections may be required. Very short time steps might be required in quick dam removal cases such as that of the San Clemente Dam on the Carmel River which is totally different than the Milltown Dam removal case.

Milltown Reservoir is a run of river system with a well developed main channel through the reservoir, as discussed in Section 2-1. Accordingly, it is quasi-one-dimensional and is a good application for a model such as HEC-6. This was also the case for the Fort Edward and Washington Water Power Dams. It has less applicability when one is modeling a broad delta deposit as was the case in the Elwha River Reservoirs. A different type of model was developed for that application which was more of a 2-dimensional application (USBR, 1996).

4.2 HEC-6 Model

4.2.1 Scenarios Evaluated

Evaluation of the potential for, and fate and transport of sediment from the reservoir, under various remedial action options, was completed in stages. Initially a comprehensive group of potential remedial action scenarios was developed and evaluated in a preliminary "feasibility study" level of detail. The results of this preliminary analysis were summarized in a report entitled "Revised Draft Technical Memorandum Milltown Reservoir Scour During Area I Sediment and Dam Removal" (Envirocon, August 2003). The August Scour Analysis focused on verifying sequencing and timing of actions relative to flow conditions to determine the optimal timing to minimize TSS concentrations. In the "Draft Technical Memorandum Milltown Reservoir Dry Removal Scour Evaluation" (Envirocon, November 2003), a partial bypass channel excavated in SAA I to divert CFR flows around the SAA III sediments designated by the EPA as having elevated metals, was evaluated and compared against some of the August models.

The scour evaluation history of the previous analyses and general conclusions is summarized in Table C-1. This evaluation builds upon what was learned in the previous evaluations and focuses on the following potential remedial action scenarios:

- Scenario 1 – models no action to provide base results for comparison to the active remedial action scenarios described below. Under the "no action" scenario the dam continues to operate at full pool water levels in the reservoir.
- Scenario 2 – models the Proposed Action described in EPA's April 2003 "Cleanup Proposal for the Milltown Reservoir Sediments Operable Unit" (i.e., EPA's 85% wet, 15% dry SAA I sediment removal remedial action). Since EPA's wet removal anticipates hydraulic dredging SAA I sediments behind a sheet pile wall at near full pool reservoir water levels, scour potential conditions for most of the Scenario 2 remedial action period are assumed to be similar to Scenario 1. However, for a portion of the Scenario 2 modeled time period it is assumed that the reservoir water level will be lowered to facilitate access for installing the sheetpile wall and removing the 15% of the sediments proposed to be removed in the dry. For modeling purposes it is assumed that reservoir drawdown will be accomplished by dropping the water surface elevation 6 feet starting in July, 2005 and extending for an approximately 9-month period after which time the reservoir will return to full pool conditions for the remainder of the dredging period (see Figure 4-1). Note that the Scenario 2 model does not address potential scour that could occur after the dam is removed. Because the dam would presumably be removed after construction of new channels upstream, and the design for these channels is still being developed, it was not possible to accurately model post-dam removal scour under Scenario 2 at this time. However, a gross estimate of additional scour volume after dam removal was made for Scenario 2 based on model results for Scenarios 3 and 4 and assumptions on construction timing and design details for new channels.
- Scenario 3 – models a dry sediment removal action that utilizes staged early dam removal to facilitate access for mechanical excavation equipment. The simulation begins on October 1, 2004, with the gradual drawdown to spillway crest by opening the radial gate. On November 1st of 2005 the model assumes flow is routed through the powerhouse with inlets converted to become low level outlets. Finally, on March 15, 2006 the dam is fully breached (see Figure 4-2).
- Scenario 4 – similar to Scenario 3, this scenario models a dry sediment removal action under staged early dam removal but assumes construction of a bypass channel that could be used to divert CFR flows around the SAA III sediments prior to dam removal. The bypass channel is assumed to be located in SAA I beginning at the BFR just below the I-90 Bridge, parallels I-90, and connects back with the CFR just above Duck Bridge (see Figure 4-3). The conceptual details and approach of the full bypass channel are shown in Figures B-1 to B-3. This conceptual design is assumed for the purposes of Scenario 4 scour modeling only and will be updated if this scenario is selected

for detailed design. The reservoir water level drawdown staging is the same as Scenario 3.

Modeled time periods for all scenarios are assumed to begin on October 1, 2004 and run for 4.3 years through December 31, 2008 to facilitate direct comparison between scenarios. The 4.3-year modeled timeframe was selected to represent the approximate amount of time required under the dry removal scenarios to dewater, preload and excavate the SAA I sediments. Under Scenarios 1, 2, and 3 it is assumed that the BFR and CFR will be flowing in their current channels (i.e., SAA III) during this entire time period, thereby exposing the channel sediments to the potential for scour. Under Scenario 4, flow will be in current channels for approximately one year prior to CFR flows being diverted to the bypass channel. At the end of this timeframe it is assumed CFR and BFR river flows would have been rerouted into their post-excavation reconstructed channels under all scenarios.

All scenarios were modeled assuming hydraulic conditions consistent with a series of average annual flows. In addition to the various reservoir operating conditions described above, the effect of different flow conditions during the modeled period were also evaluated for Scenario 4. Scenario 4a represents a series of average annual flow regimes occurring during the 4.3-year-long modeled period. Scenario 4b models a flow regime that includes a 25-year flow event hydrograph occurring post-dam removal during 2007 and average flows in the other years. The 1975 hydrograph is used to represent predicted flows during the 25-year flow event year. Scenario 4c is modeled reflecting the occurrence of low flow conditions during 2007. The 1992 hydrograph is used to represent low flow conditions.

Beyond modeling high and low flow scenarios in 2007, EPA requested additional evaluation of the effect of hydrology changes occurring during drawdown/dam removal stages on predicted TSS concentrations. In response to their request the effect of higher or lower than average flows occurring in 2005 and 2006 is being currently modeled with results to be provided as an addendum to this report. In the interim, estimates of the effect of different hydrology on TSS concentrations were made based on extrapolations from previous hydrology sensitivity analyses completed for the August 2003 report (see Table C-1).

Figures 4-4 through 4-7 graphically identify the timing of dam operational changes and the assumed reservoir water surface elevations immediately upstream of the dam over the course of the modeled period for each of the scenarios.

4.2.2 Model Development and Calibration

HEC-6 requires three groups of data for model computations: channel geometry, sediment characteristics and hydrology. Table C-2 categorizes input parameters and describes the source for each parameter used in the model.

<u>Channel Geometry</u>

Upstream of Milltown Dam, the geometry consists of up to three reaches: The CFR, the BFR, and the bypass channel used in Scenario 4. The CFR reach includes the CFR from Milltown Dam to Duck Bridge and from Duck Bridge to Turah. The BFR and the CFR reaches begin at a junction point just upstream of Milltown Dam. The BFR reach extends from the junction point upstream to Stimson Dam. (Note: potential scour of material above Stimson Dam is not evaluated in this analysis due to lack of information on the quantity and type of sediment currently located upstream of Stimson Dam. However, a sediment coring and channel bathymetry investigation is currently being completed for the BFR reach immediately upstream of Stimson Dam and it is anticipated that this will be included in future scour modeling completed for the detailed design.) Stimson Dam is modeled as a grade control structure (i.e. bed level does not change over time) as is the I-90 Bridge on the BFR, where the immovable bed elevation is set at the tie-in elevation for a future restoration channel. In Scenarios 1 through 3 and stage 1 of Scenario 4, the CFR and the BFR convey all the flow. For stage 2, the flow is routed through the bypass channel and into the powerhouse. Then, the flow is routed through the breached spillway/radial gate area in a new excavated channel in stage 3 while still traveling through the bypass channel. The model assumes instantaneous cross-section changes with no transitions between stages.

Cross section locations are shown on Figure 4-8. The topography and bathymetry of the CFR from Milltown Dam to about 1,000 feet upstream of Duck Bridge and the BFR from Milltown Dam to Stimson Dam were surveyed during the 2003 Field Sampling Event and digital contour plots were made. From these contour plots a DTM was created in the form of a Triangular Irregular Network (TIN). Once this was created, the contours were overlaid on georeference aerial photos of the study area and cross sections were cut at strategic locations. These locations include significant changes in plan form, elevation, land use, and at bridges. In general, cross section spacing was kept at 200 ft or less. There is limited available guidance on cross section spacing for dam removal studies. However, it is generally agreed that spacing should be as close as feasibly possible to minimize instabilities. For this study, cross section spacing was reduced to a point in which obvious instabilities did not occur. Once the cross sections were cut, they were imported into HEC-RAS, where bank stations, n-values, and ineffective flow areas were set. The new cross sections were then inserted into the HEC-6 input file.

To increase the area modeled to the reach of the CFR below the dam and the reach from Turah to about 1,000 feet upstream of Duck Bridge, previous surveys were used to supplement the cross section data. Some cross sections from Duck Bridge to Turah were surveyed in 1997 by Land & Water Consulting (N, EI, O, and CF90-2) using State-Plane NAD83 ground coordinates, which were converted to UTM coordinates for this analysis, and the NAVD88 vertical datum. Cross sections from upstream of CF90-2 to Turah used cross sections surveyed by Horizon, Inc., Professional Consultants, Inc., and Sorenson & Co. in 1981 and 1990. Cross sections surveyed in 1981 and 1990 using the NGVD29 vertical reference datum were adjusted to NAVD88 to maintain consistency with the current datum. It should be noted that changes in channel bed elevation likely have occurred since these surveys which would not be reflected in cross section geometry used in the modeling.

The cross sections used for the reach from near the confluence of the Bitterroot River (BR) to below Milltown Dam are composed of cross sections used in the ENSR dam break study conducted for the EPA under the “Continued Releases Work Plan for the Milltown Reservoir Sediments Site” (Environmental Toxicology International, Inc, January, 1994). These cross sections were placed at the same location as the 1988 FEMA Flood Insurance Study cross sections and generally provide a representative description of the river geometry from Milltown Dam to the confluence with the BR. The geometries of the cross sections were compiled using USGS quadrangle maps, the 1988 FEMA study and local surveys. However it was mentioned in the EPA Work Plan that these cross sections were simplified for use in the dam break study. This is particularly evident in the cross sections at the downstream end of the reach. Although very coarse in definition, it was decided that the cross sections would be sufficient for the objectives of the study, namely the semi-quantitative evaluation of downstream fate and transport of sediments. An additional cross section was added just downstream of Milltown Dam to capture the gravel bar located there. This cross section was developed using a combination of contour plots, a tailrace bathymetric survey, and field observations. Also, additional interpolated cross sections were added to reduce cross section reach lengths to less than 2,000 ft.

Bed roughness is defined by the roughness coefficient, Manning’s n. For cross sections upstream of the dam, the upper range of Manning’s n values used by FEMA in their 1988 floodplain determination modeling (summarized in the RI) were used. Manning’s n-values of 0.06 and 0.04 were assigned to the overbanks and main channel, respectively, of the downstream reach based on field observations and a review of the 1988 FEMA study. The cross section located at the gravel bar just downstream of the dam was given higher n-values (0.10 and 0.08) to account for the heavy vegetation and turbulent flow conditions there. These values are reasonable given the channel bed conditions, and overbank characteristics. Further review suggested slight adjustment of the n-values upstream of the dam to represent areas of thicker vegetation that appear on the aerial photos. The n-values were further adjusted in the calibration process as discussed in Section 4.2.2.1.

All cross section bank stations were determined by visual inspection of both the cross section itself, and aerial photos. Typically, the bank station was selected at the obvious break in grade between the main channel and the overbank area. However, in the braided section of the upper reach of the CFR, multiple channels are present and more judgment was required for bank station placement. In general, the method used to define the main channel in the HEC-6 model was to use the channel with the lowest invert elevation, and to remain spatially consistent from one cross section to the next. HEC-6 only allows one moveable bed width entry per cross section; therefore, scour and deposition will only occur in the primary channel, and not the secondary channels in the braided sections. Moveable bed limits for each cross section were set using the HEC-6 default method, which allows aggradation or degradation to occur in areas submerged by the water surface.

For the model scenarios, the sheetpile wall or flood control berm set at the top of bank of SAA I will minimally affect scour in the model because, the water surface will not typically contact the wall during the drawdown/dam removal events. Therefore, it was not included in the geometry.

For Scenario 4, a bypass channel around the existing CFR channel was used. The bypass channel reach begins at the BFR just below the I-90 Bridge. From there, it parallels I-90 and connects back with the CFR just above Duck Bridge. After the stage 1 (i.e., radial gate drawdown period) the resulting geometry and sediment gradation is copied from these cross sections on the CFR existing channel reach and inserted into the bypass channel reach. The entrance to the bypass channel is modeled as a 5 ft armored drop and is designated as grade control by manually preventing scour in the model. Downstream of the drop, a concrete apron 200 feet long is assumed. A bridge crossing the bypass channel at the apron is assumed to have a 5-foot wide pier, which is included in the model (see Figures B-1 and B-2). As previously noted, these assumptions were made strictly for modeling purposes with the recognition that alternate concepts may be developed in the detailed design provided they result in a hydraulically stable channel.

Because HEC-6 cannot handle looped river networks, the CFR cross sections between Duck Bridge and Milltown Dam were "shared" between the CFR existing channel reach and the bypass channel reach. To facilitate this, the model was run through stage 1. After stage 1, the geometry and sediment from the cross sections in the upper reservoir and upper CFR reach were copied and input to the cross sections above the bypass channel. Then the entire Scenario 4 model (all three stages) was run for final conditions. This concept is illustrated in Figure B-4.

The water surface elevations at the dam are controlled in the model as an internal boundary. In Scenario 4, the final breaching of the dam is modeled using a DREDGE card in HEC-6. The DREDGE record allows the model to modify a cross section in the middle of a run by excavating a simple trapezoidal shaped cut in the existing geometry (as would occur for actual dredging).

<u>Sediment Characteristics</u>

The inflowing sediment loads for the CFR and BFR are based on historical records available on the USGS database. The measured sediment discharge is determined by an integration of spot samples in the water column at the gage site and does not include bedload (sediment moving at bed level). Coarser sediment tends to remain on the bed and as a result does not show up in the sediment measurements. A reasonable estimate for bed load is about 10% of the total suspended load. This is a reasonable, but conservative, value based on past Corps of Engineers studies on the Mississippi and Missouri Rivers. Initially, this estimate was used to adjust the inflowing sediment loads and the bed sediment gradations in the upper reaches of the CFR and BFR. The inflowing sediment load and bed gradations were further adjusted in the calibration process to include estimated bed load. Figures C-1a and C-1b graph the USGS equations for inflowing suspended sediment as well as the adjusted total sediment load determined in the calibration process for the CFR and BFR, respectively, used in HEC-6 modeling. The total load deviates from the USGS suspended load equations at around 3,500 cfs and reaches a 10% increase at the higher flows.

Moveable bed depth from Milltown Dam to I-90 Bridge and Duck Bridge were conservatively based on the bedrock elevations in sheetpile wall corings taken during the 2003/2004 Field Sampling Event (see Figure B-5). Because the model does not allow for varying sediment layers, the alluvial gravels that underly the sediments in reservoir are not directly represented, likely resulting in the model over-predicting the potential depth and volume of scour. Sediment particle size gradation and specific gravity information was compiled from core samples taken for the 1998 Sediment and Surface Water Sampling Report (ARCO, 1998), the Final Draft Remedial Investigation (RI) Report (ARCO, 1995), and the 2002 Supplemental Data Summary Report (EPA, 2002a). At cross sections where core samples were not available, the nearest available core sample was used. The bypass channel bottom is set as a fixed bed on the assumption that the final design will result in a constructed channel that is resistant to erosion. The upper CFR reach cross-sections that are outside the influence the reservoir (as characterized by a break in gradient in the longitudinal profile) were also defined as fixed beds in the model for all scenarios. The rational for fixing the upper CFR reach cross sections is two-fold:

1. The river bed between the reservoir head and Turah is predominantly composed of coarse material (i.e., gravels and cobbles) that, although potentially not fully armored, should be much more resistant to scour than the fine-grained reservoir sediments; and
2. In sensitivity analysis modeling where the bed was not simulated as fixed the model predicted bed degradation of one to three feet in the upper CFR reach cross-sections under all modeled scenarios including no action. Given that the available cross section data shows bed elevations in that area have historically been relatively stable the model appeared to overestimate the net scour in this reach under no action, and by extension, dam removal scenarios.

Since no core samples are available in the downstream reach, an assumption had to be made regarding bed sediment gradation. Because the downstream reach is a free flowing stretch, and appeared to be fully armored during the field inspection, the bed gradations were initially set to the same gradation that was used at the upstream-most cross section (at Turah). The CFR at Turah is free-flowing, armored, and has a bed composed mostly of cobbles and gravels. The bed gradations were further coarsened in the calibration process. The sediment bed reservoir depths (depth of erodable sediment) for each of the downstream cross sections was set to 5-ft. No data was available to indicate otherwise. This was assumed to be reasonable, since mostly deposition and only minor scour was expected in the lower reach.

Yang's sand and gravel transport function was used. A comparison of the applicability of sand transport functions for a wide range of hydraulic and sediment properties was conducted by David T. Williams (Williams, David T., 1995). Based on the conclusions of this publication, Yang's transport function was the best fit for this study based on grain size, Froude Number, relative depth, and stream power in the CFR. Also the results of a site-specific sensitivity analysis identified Yang's as the preferred total load equation because it provided conservative results (see Section 4.2.2.2).

HEC-6 requires additional parameters to describe the physical processes involved in the transport of clay and silt particles. Other than the quantity of clay and silt present in the bed, there is no data to suggest representative values for these additional parameters (i.e. shear stress thresholds). In order to execute the simulations including silt and clay, values used in a sample problem in the HEC-6 manual were used. Shear stress parameters are further discussed in Section 4.2.2.2.

<u>Hydrology</u>
The hydrology records used in the development of this model can be categorized three ways: calibration, warm-up, and simulation.

For calibrating the model, the most recent 25-years (1977-2002) of historical daily average flows in the CFR and BFR were used at one day time steps. Although no historical cross sections were available in the downstream reach, it was assumed that over the last 25-years, the system has been in a dynamic equilibrium.

The "warm-up" hydrology is used for the artificial process of pre-sorting and armoring the bed material to replicate existing conditions. In HEC-6, bed gradations are initially assumed to be completely mixed. The modeler has found that for alluvial rivers, it is useful to run about 30 days at a bankful discharge (3200 cfs in the CFR, and 7600 cfs in the Blackfoot) for proper sorting and armoring to take place. This technique was used both in the calibration runs and in the simulations.

As previously noted, Scenarios 3 and 4 reflect the assumed construction schedule for the full bypass/remediation. The simulation begins on October 1, 2004, with the gradual drawdown to spillway crest by opening the radial gate. On November 1st of 2005, flow is diverted through the bypass channel and routed through the powerhouse. Finally, on March 15, 2006 the dam is fully breached and the water surface elevation is rapidly reduced to free-flowing conditions.

In general, the model is run with 0.5 day time steps. During moderate drawdown periods, the time steps are further reduced to 2.4 hours. At certain low-flow conditions and during final breaching, time steps of 14.4 minutes were required to prevent sediment fill-up. The time slicing adds stability and accuracy to the model and prevents sediment fill-up in cross sections during periods of rapid water surface elevation reduction.

Flow information used in the modeled scenarios was based on USGS gage data for the CFR at Turah, CFR above Missoula and BFR near Bonner stations. For the average annual flow scenarios the 1999 hydrograph for these stations was used. The 1975 hydrograph adjusted was used for the 25-year flow event hydrograph. The 1992 hydrograph was used to represent the low flow year option.

The downstream boundary cross section is located near the CFR's confluence with the BR. Normal depth computations were made at the cross section to determine boundary condition water surface elevations. The dam itself represents an internal boundary within the simulation, since water surface elevations will be controlled there throughout the simulation period of this model. For the internal boundary condition, various flow and dam operation conditions, rating curves provided by NorthWestern Energy were used. The dam drawdown rating curves from NorthWestern Energy were originally in a local datum, and had to be adjusted upwards by 1.979 feet to be consistent with the NAVD88 datum (additional discussion of survey history at the site and translation factors between the different vertical and horizontal datum used at the site is available upon request). Normal depth computations were made at the dam cross section to determine boundary condition water surface elevations once the dam is breached. Daily water temperatures were based on USGS monitoring data. A complete description of hydrology data used as model input is available upon request.

For Scenario 4, the bypass channel reach requires that an additional discharge and temperature record be applied for each time step. For stage 1 of the Scenario 4, the bypass channel discharge was reduced to 10 cfs (the model requires at least a minimal amount of discharge through every reach) while the remainder was input at the upstream ends of the CFR and BFR reaches. At the beginning of stage 2 (i.e., the powerhouse inlet conversion drawdown period), the CFR flow is routed through the bypass channel and the CFR is reduced to 10 cfs. The temperature used for the bypass channel was assumed to be the same as the temperature in the CFR reach.

4.2.2.1 Model Calibration

Calibration is a necessary procedure to provide confidence in the model results when using HEC-6. This is particularly important for this study due to the limited sediment data available, the unknown bedload inflow, and the geometric assumptions made in the braided section of the CFR.

The CFR upstream of Milltown Dam has been flowing in dynamic equilibrium for over 25 years, as is evident by examination of historical changes in cross section geometry. Dynamic Equilibrium is defined as a physical state of a river in which its morphology is active, yet there is no appreciable net annual scour or deposition. Under this assumption, a simulation covering the past 25 years of historical records should show no significant net scour or deposition throughout the study area. By running the HEC-6 model for the last 25 years of hydrologic record, and adjusting the input parameters that have some uncertainty associated with them, a similar dynamic equilibrium was achieved.

In general, adjustments were made in the calibration process in the following order:

- The inflowing sediment load on the CFR was increased by roughly 10% and coarser material was added (see Figure C-1a). This helped to prevent overall degradation.
- Because the upstream boundary of the BFR reach of the model is at Stimson dam, it was assumed that much of the coarser material settles out and doesn't enter the model study reach, particularly at low flows. The inflowing load curve was skewed to allow coarser material to pass at higher flows, while preventing it from entering the system at lower flows (see Figure C-1b). This was adjusted repeatedly before a dynamic equilibrium was achieved.
- In the upper reaches of the CFR, the bed gradations were adjusted to be coarser. This prevented localized net degradation in the upper reaches.
- Just upstream of Milltown Dam, the conveyance widths and moveable bed widths were reduced. This helped to simulate the presence of ineffective flow areas (slack-water zones) in the reservoir and prevented localized aggradation.

Roughness coefficients (n values) were increased slightly in the upper reaches of the CFR. This helped to increase the flow depths, which reduced the amount of degradation. It is logical to have higher n values in the upper reaches, as the depths are shallower than in the reservoir, and the bed roughness has more effect on energy loss. In areas where the river is channelized, such as the BFR and the uppermost cross section of the CFR, the n values were decreased.

By adjusting n-values, ineffective flow area, and moveable bed limits, this model was calibrated, with the majority of the cross sections showing less than 1 foot of bed elevation change. Six cross sections in the upper CFR reach showed net scouring of a little more than 1 foot. Considering the morphological changes that have occurred over the last 25 years, these values are reasonable. The parameters adjusted in the calibration process were kept within realistic ranges.

4.2.2.2 Sensitivity Analysis Results

HEC-6 sensitivity analyses were performed to assess the confidence in the estimates produced by the initial model runs. Table C-3 describes the range of parameters used in the sensitivity analysis and calibration. The effects of sediment transport functions, shear stress thresholds, and gradation ranges in the Blackfoot were tested in the sensitivity analysis. Water Year (WY, note that consistent with USGS protocols, water years extending from the preceding October through the following September, rather than calendar years, were used in the sensitivity analysis) 2002 was modeled for 1 year using the actual flow regime and reservoir stage for the sensitivity analysis comparison. This year was chosen because there is a drawdown event that occurs in August causing significant TSS peaks. The downstream boundary of the model was set at the FEMA cross section closest to the CFR above Missoula gage. The percent difference between the model cumulative tons and the measured cumulative tons were calculated, and the standard deviation of the error between the daily predicted TSS and measured TSS were also calculated. These two parameters were used to determine sensitivity.

HEC-6 allows the user to specify sediment transport of particles in the sand and larger class sizes by several different relationships. All total load equations available in HEC-6 were run for this model. Only four equations tested were stable under the parameters of this model. The stable equations were then used for the sensitivity analysis and included the following:

- Yang
- Madden 1963
- Madden 1985
- Copeland

The Yang and Madden (1963 and 1985) equations all over predicted sediment volumes and TSS (see Table C-4 and Figure C-2). Copeland actually is closest in its ability to calculate volume and TSS, but has a tendency to underpredict. Yang was determined to provide the best sediment transport estimation because it yielded the closest approximation of the downstream sediment load and peak TSS without underpredicting.

As a supporting sensitivity analysis check on the sediment transport equations, Water Year 1999 was modeled using the two best sediment transport functions from the 2002 sensitivity analysis. This sensitivity was chosen to provide the bounds to the scenarios modeled as they all use Water Year 1999. Table C-5 and Figure C-3 confirm that, while Copeland is a better predictor for sediment volumes and TSS, it can underpredict, and therefore Yang is the conservative choice. To extrapolate from the sensitivity analysis using Yang, one can expect to see the model over predict the sediment volume by 33% per year and the TSS by up to 150 mg/L. When instabilities in the model occur, over predictions of up to 2,000 mg/L of TSS can occur.

As part of the 2002 sensitivity analysis, a test was performed in which the shear stress threshold parameters for erosion and deposition were increased by 100% and also reduced by 50%. The results of this sensitivity test indicate that the concentration of fine sediment can vary positively or negatively by as much as 252 mg/L when using the higher critical shear stress for erosion (See Figure C-4). The predicted volume differences were minimal (see Table C-6). Overall, changing the critical threshold value did not have a large influence on the predictions as compared to the error already introduced in the model as seen in the sediment transport function analysis. This shows that the range of shear stress values reasonable for reservoir sediment type materials is low enough that the sediment would be predicted to move regardless of the specific value within this range selected for use in the model.

Since HEC-6 has a limitation of one sediment size gradation configuration for a given cross section, a sensitivity analysis evaluating the effect of variation in assumed sediment particle size gradation on predicted TSS concentrations and total scour volumes was also performed. The sediment gradation sensitivity analysis involved running the model for simulated water year 2002 hydrology and drawdown conditions using two different assumed sediment gradations. The gradations chosen represented the coarsest and finest gradations found in the EPA 2002 sediment core samples. It was found that there was little difference in the predicted total scour volumes and TSS concentration variations between the two model runs (see Figure C-5 and Table C-7). Both over predicted measured volumes by about 32-33% and both over predicted the measured peak TSS concentration by about 115 mg/L. Based on these results, it can be concluded that for the range of gradations observed in Milltown Reservoir sediment, there would be no significant difference in predicted TSS release rates or volumes as scour proceeded deeper potentially encountering sediment with slightly different gradations. Therefore the HEC-6 limitation of a single sediment gradation per cross-section is not considered to significantly affect the accuracy of predicted results for sediment scour. However, as discussed further in Section 4.2.4, the insensitivity of model predictions to sediment gradation variations does not mean it would be insensitive to the much greater gradation variations between sediment and the underlying gravel/cobble alluvium.

4.2.3 Model Results

Scenario 1 (i.e. no action) model results predict a net deposition upstream of Milltown Dam of approximately 20,000 tons (equivalent to approximately 17,000 in-place cy when converted using average dry density of sediment samples) over 4.3 years of average flows with a peak predicted downstream TSS concentration of 1,086 mg/L (see Table 4-1 and Figure C-6). This predicted peak TSS concentration was determined to be an initial conditions effect of model startup rather than a meaningful result. This conclusion was based on the fact that further reducing time step interval length during the warm up period to 0.1 days eliminated the TSS peak discrepancy. The peak TSS concentration predicted after the initial condition effect was 292 mg/L and occurred during the third year high-flow period. By comparison, the actual highest observed TSS concentration from 1999 was 162 mg/L, suggesting the model was over predicting peak TSS during average flow, full pool conditions by approximately 130 mg/L. As shown on Figure 4-9 only fine-grained sediment is predicted to scour, 99% of which is predicted to come from the CFR limb.

Scenario 2 (i.e. EPA’s Cleanup Proposal Proposed Action) estimates approximately 48,000 tons (41,000 cy) will scour from upstream of Milltown Dam over the 4.3 year-long modeled excavation period under average flows (Table 4-2a). There is no significant difference in predicted magnitude of peak TSS concentrations during the modeled period when compared to “No Action” Scenario 1 (Figure C-7), but the predicted peak occurs during the drawdown instead of the high-flow period (disregarding the 1,086 mg/L peak TSS predicted under Scenario 1 due to initial conditions). Similar to Scenario 1, little scour is predicted in the BFR limb and only scouring of fines is predicted during the modeled period (as Figure 4-10 shows). As previously noted, Scenario 2’s model only evaluated predicted scour during the sediment excavation construction period and therefore does not included additional scour that may occur after new channel reconstruction and dam removal. Given that the new channel construction is unlikely to prevent scour on the BFR after dam removal and may not be completed in time to mitigate scour on the CFR above Duck Bridge, it is probable that an additional up to 320,000 tons (270,000 cy) would scour after dam removal. As shown in Table 4-2b, adding the estimated post-dam-removal scour to the model-predicted pre-drawdown removal scour suggests total scour under Scenario 2 could be as much as 370,000 tons (310,000 cy). Although not modeled, peak TSS concentrations post-dam removal under Scenario 2 are likely to be similar to Scenario 4 results.

Scenario 3 (i.e. dam removal to support dry sediment excavation without bypass) predicts a peak TSS concentration of 4,386 mg/L with a predicted scour volume of 1.2 million tons (1.1 million cy) from upstream of Milltown Dam over the 4.3-year modeled period (Table 4-3 and Figure C-8). The CFR limb between Milltown Dam and Duck Bridge provides 73% of the predicted scour volume (Figure 4-11).

Scenario 4a (full bypass channel) model results predict total amount of sediment scoured from above Milltown Dam through the 1,582-day simulation period under average flows is 478,000 tons (406,000 cy) (Table 4-4). For comparison as noted in Section 3.1, Scenario 4a's predicted total amount of scour over 4.3 years is considerably less than the 762,000 tons of total sediment load USGS measured at the CFR above Missoula gage during just two recent years, 1996 and 1997. Figure 4-12 shows that 29% of the sediment scoured comes from the CFR limb between Milltown Dam and Duck Bridge. The upper CFR and the BFR accounted for 20% and slightly over 50%, respectively.

Predicted sediment concentrations at the current location of Milltown Dam under Scenario 4a show three distinct peaks, all results of staged drawdown events (Figure C-9). The first drawdown in stage 1 produced a predicted peak sediment concentration of 1,049 mg/L. The second drawdown in stage 2 produced a predicted peak of 1,219 mg/L and the third resulted in a predicted peak of 1,854 mg/L. Comparison of Scenario 4a predicted TSS concentrations against proposed temporary construction-related water quality standards identified on Table 1-3 shows TSS concentrations exceeding the 550 mg/L short-term (day) standard on 12 days including 3 days following radial gate drawdown, 4 days following powerhouse inlet conversion drawdown and 5 days following dam removal. Predicted TSS concentrations decreased to below the 170 mg/L mid-term (week) standard within 1 to 2 weeks and below the 86 mg/L long-term (season) standard within 1 to 3 months of each drawdown. The HEC-6 predicted peak TSS concentrations are considered conservative given the previously noted assumptions built into the model such as limited staging of drawdown, use of the more conservative Yang equation, and not differentiating coarser-grained alluvial material from the fine-grained gradation selected to be representative of overlying reservoir sediments.

Under Scenario 4b, when Water Year 2007 is assumed to have a 25-year flow event, TSS concentrations reached approximately 400 mg/L and predicted net scour over the modeled period was similar to Scenario 4a's results for average flows except for a slight reduction in estimated net scour on the CFR limb upstream of Duck Bridge (Figure C-10 and Table 4-5). As discussed further below, this reduction in net scour results from net deposition of sediment coming from upstream during the falling limb portion of the 25-year flow event rather then from any reduction in predicted scour during the drawdown and dam removal period. Under Scenario 4c, when Water Year 2007 has a low flow event, there is little effect on predicted TSS and net scour quantities (Figure C-11 and Table 4-6). To further compare the effects of the different flow events, Figures C-12 through C-14 break out predicted net scour volume by year. Net deposition in some reaches during Water Year 2007 is clearly shown for Scenario 4b, suggesting that a high-flow event occurring towards the end of the construction period may result in overall net deposition of sediment from upstream. Changing the flow in 2007 also has some effects on Water Year 2008. Actual modeling of the effect of flow variation during, rather than after, the assumed drawdown and dam removal implementation period (i.e., fall 2004 through spring 2006) is currently being completed. However, based on previous modeling of flow variation sensitivity under other assumed dam removal staging scenarios, if high flow events occurred in Water Year 2005 or 2006 when drawdown and dam removal are being implemented, dilution from higher flows would likely supersede the increased load (previous modeling found TSS concentration to decrease by half when flows were six times higher). Alternatively, the previous modeling results predicted slightly higher peak TSS concentrations if drawdown/dam removal was implemented during low flow conditions.

Figure 4-13 provides a condensed summary of the results for total estimated sediment load during the highest load year over the modeled period compared between all scenarios. The portion of this total load coming from net scour of reservoir sediments versus sediments coming down from upstream of the reservoir is broken out on this figure. For comparison, measured sediment loads are also shown for 1996 (ice scour year), 1997 (high flow year) and for average 1991-1995 and 1991-1997 conditions. Figure 4-14 graphs the peak TSS concentrations predicted under each scenario. Measured peak TSS concentrations for 1996 and 1997, as well as measured and modeled peak TSS concentrations for the 2002 and 1999 sensitivity analysis, are also shown on Figure 4-14 for comparison.

Predicted cumulative deposition of sediment in the downstream reach is plotted for Scenario 4a. There is a sudden peak in predicted deposition in the downstream reach at the beginning of stage 3. The cumulative deposition of about 160,000 tons equates to about 136,000 cy of sediment accumulated. However, that accumulation of sediment is quickly scoured away in the succeeding high flow event. This suggests that strategic timing of the drawdown events with the high flow periods will help to minimize the amount of deposition in the downstream CFR reach.

The results of the HEC-6 modeling of the reach below Milltown Dam suggests that the fine material (clays and silts) will move through the reach as wash load. Travel time from Milltown Dam to the BR confluence for the fine material is estimated to be 1 day or less. Sand sized sediment will generally remain in suspension throughout the entire downstream reach, but will temporarily deposit at significant constrictions. The model indicates that little to no dilution of the fine material is expected between Milltown Dam and the BR. Significant dilution of the sand concentration is expected in the first two years, during low flow periods. Undoubtedly, local backwater eddies, sloughs, ineffective flow areas, etc., are present in the reach between Milltown dam and the confluence with the BR. Although the model cannot show this, given it is one-dimensional, it is expected that some of the coarser material will deposit in these local areas of low conveyance. Deposition in these areas will not significantly reduce the efficiency of the channel to pass flow.

The HEC-6 model output indicates that all sand-sized particles will remain in suspension throughout the lower reach, except at cross section 361.36, which represents a chokepoint in the river, caused by the I-90 bridge constriction. An incipient motion analysis was performed throughout the lower reach and this finding was confirmed, as presented in Figures 4-16 and 4-17. These figures indicate that, with the exception of cross section 361.36, all particles smaller than 4mm will remain mobile, and all particles smaller than 1 to 2 mm will remain in suspension. Particles between 0.0625 and 2.0 mm are sands.

Cross section 361.36 is important to consider, as it represents what is likely to happen at significant choke points along the downstream reach. Fortunately, this choke point was accurately represented in the cross sections that were available, but there are most likely other choke points that were not captured in the geometry used in this model. Figure 4-18 shows the river profile in the vicinity of cross section 361.36. Historically, a break in grade has been building up over time due to the constriction imposed by the I-90 bridge at East Missoula. This is evident in the existing bed profile where the bed is near horizontal for about 0.6 miles. As Figure 4-18 illustrates, approximately 1.5 ft of sand will deposit in the low-velocity reach upstream of the bridge by the end of stage 2. During subsequent high flow periods of years 2 and 3 the majority of the deposited sediment is scoured out, returning the bed profile nearly back to its original condition. So although deposition should be expected upstream of significant chokepoints, the deposited sediments are likely to be scoured away after one or two water years.

Longitudinal profiles for each reach were plotted in Figures 4-19 through 4-23 to examine the extent of the scour depths and view the change in gradient and how it ties into other reaches.

4.2.4 Discussion

Overall, the HEC-6 modeling effort identified that scour and increase in downstream TSS concentrations are likely to occur under any of the dam removal options with the dry removal scenarios potentially resulting in somewhat greater amounts of scour. However, by routing flows through a full bypass channel before the dam was removed, Scenario 4a reduces CFR sediment scour by up to 600,000 cy compared to Scenario 3, with the remaining approximately 400,000 cy of scour limited to lower metals concentration sediments. By comparison, the equivalent of approximately 650,000 cy of sediment moved through the reservoir in 1996 and 1997 water years.

These predicted scour volumes are very conservative. Not only is it expected based on sensitivity analysis results that scour quantities and TSS concentrations could potentially be over predicted by about 33%, but in Scenarios 3 and 4 where scour is cutting into gravel layers that are not considered in the single layer HEC-6 model, the predicted scour volumes would likely be even more conservative. For example, in the full bypass channel scenario, approximately 77,000 and 130,000 cy of net scour were predicted for the BFR reaches from Milltown Dam to I-90 and from I-90 to Stimson, respectively. The amount of these scour volumes made up of gravels was estimated for the two reaches by multiplying the area of gravel depth scoured in the longitudinal profile (see Figure 4-20b) by the average channel width. The estimated volume of gravels scoured in the Milltown to I-90 and I-90 to Stimson reaches were 32,000 cy and 30,000 cy, respectively. It would appear that approximately one third of the estimated BFR reach's scour volume is gravel material that the model, due to its single gradation limitation, misrepresents as fines. In reality, gravels would have much more resistance to scour; therefore, bed scour depths and hence total scour volumes predicted in the model are overly conservative. Figure 4-24 illustrates this with the model predicting greater than 20 feet of scour at this cross-section (which is located on the lower BFR downstream of I-90) with the maximum scour depth nearly reaching bedrock based on the assumption of fine-grained sediment gradation. However, as shown on Figure 4-24, top of gravels are found (based on tile probe data collected at the thalweg of each cross section) at approximately 10 feet below the existing channel thalweg elevation indicating only about 10 feet of the fine-grained sediments are actually present at this location.

Once scoured from the reservoir, the results of this HEC-6 model analysis suggest that fine sediment (clays and silts) will remain as washload in the downstream reach for all flow conditions modeled. The smaller sand particles will also remain in suspension throughout, but coarser sands are expected to deposit temporarily in the downstream reach and then move through as both bed load and suspended load. A power relationship for bed load transport was developed by Simon, Li and Fullerton (Simon, Li, and Associates, 1982) based on velocity and depth of flow. Applying this sediment transport power relationship to the coarser material it was found that the coarse sands may take up to 1 year to move through the Clark Fork reach below Milltown dam to the BR confluence based on average flow conditions. The same analysis indicates that the coarse sands can take up to 10 to 11 years to travel the 150 miles from Milltown dam to Thompson Falls Reservoir.

5 Released Sediment Fate and Transport Downstream of Dam

5.1 Evaluation of Sediment Downstream Transport

Concerns have been expressed about potential impacts associated with downstream transport/deposition of sediment that could be scoured from Milltown Reservoir during a sediment/dam removal remedial action. Some sediment will be released under any of the available remedial alternatives, thus the consequences of their release have been evaluated for the proposed approach. This section provides an overview of river geomorphology and sediment transport properties of the reach of the CFR from Milltown Dam through Thompson Falls Reservoir. In addition, while the proposed bypass channel (Scenario 4a) limits scour to sediments with background metals concentrations, an evaluation of predicted arsenic and copper concentrations in sediment potentially transported downstream to Thompson Falls Reservoir has been made.

Geomorphic and Analytical Analyses from Milltown Dam to Thompson Falls Reservoir

Appendix Figures D-1 through D-4 show the reach of the CFR from Milltown Dam downstream to Thompson Falls Dam. Milltown is approximately 150 river miles upstream of Thompson Falls as shown on USGS quadrangle maps. The thalweg profile of this entire reach is shown in Appendix Figure D-5. Tributaries are identified in Appendix Figures D-1 through D-5 and mainstem and tributary stream gages are identified in the following table. The reach between Thompson Falls Dam (designated Mile 0.0 for the purposes of this analysis) and approximately Mile 120 is basically a single thread channel in a narrow mountain valley confined by Interstate 90 and the Burlington Northern Railroad. The exception to this is the small valley at the town of Plains (River Mile 28), downstream of the Flathead River. At approximately River Mile 125 the river daylights from the canyon and enters the valley where Missoula is located. This reach from R.M. 125 to 138, the confluence with the BR, is a meandering or multi-thread channel. At R.M. 138, just upstream of Missoula, the CFR re-enters a canyon reach and Milltown Dam is located at Mile 152.

USGS STREAMGAGE	PERIOD OF RECORD	DRAINAGE AREA (SQ MI)
Thompson River	1911-2002	672
Clark Fork Nr. Plains	1910-2002	19,958
Flathead River at Perma	1983-2002	8,795
St. Regis R. Nr. St. Regis	1910-2002	303
Clark Fork Nr. St. Regis	1910-2002	10,709
Dry Cr. Nr. Superior	1982-1990	46.3
Nine Mile Cr. Nr. Huson	1973-1983	170
Clark Fork Below Missoula	1929-2002	9,003
Bitterroot River Nr. Missoula	1898-2002	2,814
Rattlesnake Cr. At Missoula	1899-1967	79.7
Clark Fork Above Missoula	1929-2002	5,999

Historic suspended sediment data were collected by the USGS at five gages: the CFR at St. Regis, the CFR below Missoula and above Missoula, the BR near Missoula and the Flathead at Perma. Suspended sediment rating curves plotting suspended sediment load (tons/day) against streamflow (cfs) were developed for these gages and are presented in Appendix Figures D-6 through D-10. Figure 5-1 depicts all of these rating curves consolidated on one figure for comparison. A total sediment rating curve was developed using the preliminary results for the HEC-6 output at the downstream end of the CFR model near the BR confluence and is presented in Figure 5-2.

As indicated in a previous section, the hydrograph for WY 1999 was selected to approximate an "average" year in the Clark Fork Basin for use in the HEC-6 model. To give the reader a comparison of the differing hydrology upstream of each gage an "average" annual hydrograph using the WY 1999 flows was developed and is presented in Appendix Figure D-11.

From the above information some qualitative suspended sediment comparisons can be made from the rating curves. The two highest rating curves are for the BR and the CFR above Missoula. The CFR below Missoula and at St. Regis have lower measured suspended sediment loads than the previous two curves, but all four gage rating curves are relatively close to one another. The Flathead at Perma has a much lower suspended sediment rating curve, which is to be expected due to the regulatory effects of Flathead Lake and Hungry Horse Dam. Fine sediments will be trapped in both lakes, reducing downstream suspended sediment loads.

By comparing the average hydrographs and the suspended sediment rating curves the following conclusions can be made:

1. The CFR above Missoula and the BR gage stations have similar hydrographs and suspended sediment rating curves, but the BR has a watershed half the size of the CFR above Missoula. This would indicate that the BR is a significantly greater source of sediment supply than the CFR above Missoula.

2. The average hydrographs for the CFR below Missoula and at St. Regis are greater than the upstream CFR above Missoula or BR hydrographs and their suspended sediment rating curves are lower. This would indicate that suspended sediment supply is limited downstream of the BR. As the Flathead is the major tributary and has limited sediment supply this seems reasonable. Accordingly, the greater flows downstream of the BR dilute the suspended sediment concentration and loads are smaller for similar flows.

3. From 1 & 2 above, the major sources of suspended sediment to the downstream CFR are the BR and the upstream CFR. The largest source would appear to be the BR.

Another assumption that is reasonable based upon the HEC-6 results and a qualitative assessment is that silts and clays act as washload and do not deposit reachwide, rather only in localized slow-water areas such as backwater eddies, point bars, and other ineffective flow zones. If one assumes that a mean velocity of 5 feet/second transports the fines over the 152 miles from Milltown Dam downstream to Thompson Falls Dam, the washload travel time would be approximately 44.5 hours.

<u>Predicted Copper and Arsenic Concentrations on Sediment Potentially Transported into Thompson Falls Reservoir</u>

Approximate total copper and arsenic concentrations on the sediment grains that could potentially be transported downstream to Thompson Falls Reservoir can be estimated using a simple mass balance model that considers the effects of dilution of scoured sediment copper and arsenic concentrations by sediment load that enters the CFR in the intervening reach. Based on a worse case scenario for average flow, if we assume that all of the sediment predicted to be scoured from the Milltown Reservoir under Scenario 4a reached Thompson Falls Reservoir and similarly assume that the other contributing tributaries convey their typical sediment loads into the CFR and these loads also all reach Thompson Falls Reservoir, over the 4 year sediment/dam removal period less than 0.5 million tons of the total sediments entering the Thompson Falls Reservoir would be predicted to be coming from scour of Milltown Reservoir sediment compared to over 2.2 million tons of the total sediment entering Thompson Falls Reservoir coming from other sources (Table 5-1). This amount of potential sediment load entering Thompson Falls Reservoir from scour of Milltown Reservoir sediments over the sediment/dam removal period is highly conservative because:

1. as previously noted, the HEC-6 model of the reservoir area used conservative assumptions for input parameters;
2. it ignores the additional sediment load entering the intervening reach of the CFR from ungaged tributaries and bed/bank erosion;
3. it assumes no loss of scoured sediment due to deposition in the intervening reaches (note: The Continued Releases Risk Assessment [EPA, 1994], where sediment downstream transport/deposition under a dam failure scenario is modeled, predicted some deposition of scoured sediments upstream of the BR confluence); and
4. the Milltown Reservoir scour quantity is limited to the construction period while the over 500,000 tons/year from other sources continues indefinitely making the fraction represented by Milltown Reservoir scour relatively insignificant over the long-term.

In addition, given the fine-grained size of suspended sediment from Milltown Reservoir that could potentially reach Thompson Falls Reservoir, it is likely that much of it would pass through rather than deposit in the reservoir. Predicted sediment loads entering cannot be compared to the amount of sediment currently in Thompson Falls Reservoir because an estimate of current impounded sediment volume could not be obtained from the dam owner.

Predicted copper and arsenic concentrations on the sediment entering Thompson Falls Reservoir over the 4 year sediment/dam removal period can be estimated by assigning typical copper and arsenic concentrations to the various sediment sources and calculating average concentrations weighted by percentage of the total amount of predicted TSS input to the reservoir. Table 5-1 summarizes the estimated TSS load to Thompson Falls Reservoir (conservatively assuming as noted above the entire estimated input to the CFR is transported to the Thompson Falls Reservoir) and corresponding assumed copper and arsenic concentrations for each TSS source. Under Scenario 4a, where a bypass channel is used to divert CFR flows below Duck Bridge, the average copper and arsenic concentrations on TSS of the Milltown Reservoir scoured sediments are estimated to be approximately 232 mg/kg and 34 mg/kg, respectively. These estimated concentrations are less than typical concentrations on TSS coming down the CFR upstream of the Milltown Reservoir. For the purposes of this analysis the major gaged downstream tributaries (i.e., the Bitterroot and Flathead Rivers) are assumed to have negligible copper and arsenic on TSS grains. Averaging input values would predict, under the worst-case scenario for average flow, that sediment reaching Thompson Falls Reservoir would have copper and arsenic concentrations on TSS of approximately 101 mg/kg and 25 mg/kg, respectively (based on a weighted average of the predicted sediment loads from the major sources calculated over the 4-year excavation period). Again, this estimate would be highly conservative because in addition to the conservative assumptions made for estimating Milltown Reservoir scour volume identified above, the assumed copper and arsenic concentrations used for scoured Milltown Reservoir sediment are likely overestimated given that they represent average concentrations for SAA III, which includes both the BFR and CFR channels, while with the bypass channel a greater percentage of scour is predicted to come from the BFR channel, with its lower metals concentration sediments. For comparison, the approximate average total copper and arsenic in existing Thompson Falls Reservoir sediments are estimated to be about 88 mg/kg and 8.9 mg/kg, respectively (see University of Montana, "Copper, Zinc and Arsenic in Bottom Sediments of Clark Fork River Reservoirs", prepared by Johns and Moore in 1985). Note that average total copper and arsenic concentrations in Thompson Falls Reservoir sediment were extrapolated from the acetic acid extractable concentrations presented in the University of Montana paper (see Table 5-1, note 5 for explanation of the total acetic acid extractable concentration extrapolation methodology).

5.2 Predicted Total Metals Concentrations in Downstream Surface Water

Predicted downstream total metals concentrations during the various dam removal scenarios cannot be directly modeled in the HEC-6 sediment transport evaluation, but can be estimated by correlation to the surface water TSS concentrations predicted by the model. The highest metals concentrations in the surface water column attributable to net scour of reservoir sediments and related increase in downstream TSS concentrations are presumably going to occur immediately below the dam. Therefore, the USGS data set for the first downstream station, CFR above Missoula, was used to determine a relationship between total metals and TSS. Data below detection limits were set at one-half detection limit for purposes of analysis. Simple correlation analysis between parameters was conducted using Pearson test of significance (2-tailed, significance = 0.05). Total arsenic and copper concentrations had strong correlations to TSS concentration.

Total metals and TSS data were fit with a linear regression (Figures D-12 and D-13) as a tool to predict total metals concentrations from TSS results of HEC-6 model runs. The linear regressions of total metals concentrations against TSS concentrations had R^2 values of 0.66 for total arsenic and 0.67 for total copper. However, very few data were available for TSS concentration values greater than 200 mg/L. This results in some uncertainty in the regression equations when they are applied outside the range of valid observations.

Based on the Scenario 4a model predicted peak TSS results of 1,854 mg/L, predicted peak downstream total arsenic and copper concentrations are estimated to be approximately 90 *u*g/L and 550 *u*g/L respectively as shown in Figure 5-3. The predicted ranges of total arsenic and copper concentrations under the Scenario 4a model are 4 to 90 *u*g/L and 7 to 550 *u*g/L, with averages of 6 *u*g/L and 22 *u*g/L, respectively. For comparison, maximum total arsenic and copper concentrations measured at the CFR above Missoula station during the 1996 ice scour event were 69 ug/L and 400 ug/L, respectively.

5.3 Predicted Dissolved Metals Concentrations in Downstream Surface Water

As identified in previous EPA risk assessments dissolved, rather than total, metals concentrations are of primary concern from an aquatic risk standpoint. Therefore, to support the downstream risk assessment an analysis was performed to better define site-specific water quality relationships between the TSS concentrations predicted in the sediment scour and transport modeling and dissolved metals concentrations. Predicted dissolved metals concentrations were estimated based on HEC-6 modeled suspended sediment concentrations for Scenario 4a, the bypass channel option. The following methods were used to determine the dissolved arsenic and copper concentrations during the proposed remedial action:

1. Regression analyses using different data sets including:
    a. Mixed surface water quality data sources (USGS, MPC, Missoula County)
    b. USGS surface water quality data set regression
    c. Mixed surface water quality data set parsed for drawdown when reservoir is a net contributor to downstream TSS load
2. Partitioning coefficients (K_d) based on different data including:
    a. EPA October 2003 K_d based on Dredged Elutriate Tests [(DRET), EPA, 2003b] in SAA III sediment/river water mixtures
    b. Water column K_d from the U.S. Army Corps March 2002 Dredging Contaminant Release Evaluation (EPA, 2002b)
    c. SAA III sediment upstream of bypass channel K_d using data from cores VC-2 and VC-3 sampled by ENSR for the remedial investigation (ARCO, 1995).

For the mixed data sources regressions, data included USGS depth integrated samples, Montana Department of Environmental Quality (MDEQ) grab samples, Montana Power Company (MPC) project data, Missoula County Health Department grab samples, and project data from consulting firms Camp, Dresser, McKee, ENSR Consulting, and CH2M Hill (Table D-1). Data varied widely in sampling frequency and parameters sampled depending on data source. Locations considered in this analysis were the CFR 2.8 miles below Milltown Dam (i.e., above Missoula, USGS station 12340500), and sampling locations in the immediate vicinity of Milltown Dam (MPC, Missoula County Health Department).

Data were merged into an SPSS database for statistical analysis. With the exception of MPC and Missoula County data, most of the information considered in this analysis was available through the MDEQ database. Data below detection limits were set at one-half detection limit for purposes of analysis. In some cases, a metal had a variable detection limit depending on data source. While this biases parametric analyses of low concentration values, the influence on the following analyses for water quality excursions is negligible.

Dissolved metals to TSS concentration relationships were modeled using linear regression. Data for dissolved metals concentrations that did not include associated TSS concentration data could not be used in this analysis (e.g. Missoula County Health Department). Data generated by MPC during drawdown monitoring were included in this analysis. Confidence intervals for mean response and individual observations were generated at the 95% confidence level.

Simple correlation analysis between parameters was conducted using Pearson test of significance (2-tailed, significance = 0.05). All parameters with listed correlations were significant at 0.05 unless noted (Table D-2, Figures D-14 and D-15).

Dissolved arsenic and copper concentrations were positively correlated to suspended sediment concentration. Correlations with TSS were generally weak for all dissolved metals. Poor correlation resulted from a variety of factors including: 1) the inherent lack of correspondence between dissolved constituents and particulate TSS fractions, 2) variability introduced by pooling both drawdown and normal flow regime datasets, 3) natural variability.

Statistically significant dissolved metals and TSS correlations were fit with a linear regression as a tool to predict dissolved metals concentrations from TSS results of HEC-6 model runs. Significant unexplained variability existed in these relationships, resulting in wide confidence intervals for individual predictions (Table D-3).

The linear regressions of dissolved metals concentrations against TSS concentrations had fairly poor fits to the data. In addition, few data were available for TSS concentration values greater than 200 mg/L. This results in significant uncertainty in the regression equations when they are applied outside the range of valid observations. Predicted dissolved metals concentrations, and the upper and lower 95% confidence intervals are found in Figures D-16 and D-17.

Regression analysis was performed on the USGS data set to see if consistent location and data sampling and analysis protocol could provide better correlations. Figures D-18 and D-19 provide the results. Slightly better correlation was found in the dissolved arsenic regression and the dissolved copper regression was quite a bit stronger than the mixed data set. Dissolved metals predictions from the USGS regressions face the same limitations as the mixed data set.

Effects of drawdown on reservoir sediment release were examined to determine if there would be better correspondence between dissolved metals and TSS during the periods when the reservoir was drawn down and upstream/downstream sampling showed the reservoir to be a net source of TSS. The mixed water quality data set was parsed to include only data collected during drawdowns, to exclude ice scour events, and the 2002 and 2003 drawdown data were added. The results of the analysis are summarized in Figures D-20 and D-21. Dissolved arsenic was more strongly correlated in the drawdown data set than the mixed and USGS only data sets. However, the data set is limited to a maximum TSS value of approximately 160 mg/L; extrapolating beyond 160 mg/L would be questionable. Dissolved copper had a negative correlation in this data set due primarily to the low dissolved copper concentrations measured during the 2002 drawdown when TSS concentrations were high. This negative correlation may partially be an artifact of the lower detection limits for metals associated with the one recent 2002 sampling analysis event and is, therefore, not considered to be a good prediction tool.

Dissolved metals concentrations were also predicted based on dissolved:total metals partitioning coefficients (also known as distribution coefficients of K_d) using three different data sources. The partitioning coefficient method was previously used by the Army Corps of Engineering (Corps) to estimate contaminant release from dredging (See the Milltown Combined Feasibility Study) and to estimate contaminant concentrations due to scouring or resuspension of Milltown Reservoir SAA III sediments (See the October 2, 2003 EPA Memorandum). The method uses the following equation:

$$\text{Dissolved Concentration} = \text{Total Concentration} / [1 + (K_d \text{ x TSS})]$$

One source used for predicting dissolved metals concentrations using partitioning coefficients was the October 2003 EPA Memorandum where the K_d was based on the DRET and MET tests in SAA III sediment/river water mixtures (Cores 1B, 2A, 3, 4, and 5) from the November 2002 EPA Supplemental Data Summary Report. The sediment contaminant concentrations and the K_d were based on the composites of the five cores, all of which are located in the lower CFR reach that will be bypassed for the majority of the construction period under Scenario 4a. In this analysis, the total metals were calculated by multiplying the mean sediment contaminant concentrations by HEC-6 predicted TSS concentrations. This data set is potentially biased because it used samples from the higher metals concentration portion of SAA III, where sediment scour is mitigated under the bypass scenario. Therefore, this data source may not be applicable for predicting but may provide some additional context on the range of predicted metals concentrations at the site.

Another partitioning coefficient calculation used was the mean water column K_d developed by the Corps for the dredging resuspension impact evaluation included in the

Combined Feasibility Study. The total metals concentrations required in this analysis to predict dissolved concentrations were calculated using USGS data regression equations, which had strong correlations with TSS, as explained in Section 5.3.

The third partitioning coefficient was calculated using the ratio of sediment total metals to pore water dissolved metals concentrations observed in the ENSR VC-2 and VC-3 samples from the RI. Similar to the EPA DRET/MET samples, VC-2 and VC-3 samples are located in the portion of SAA III that would be bypassed during most of the construction period under Scenario 4a. However, total metals concentrations in these cores are generally lower than the EPA samples and are within the range of sediment that could be scoured from the CFR existing channel upstream of Duck Bridge or the upper layer of sediment from the CFR existing channel between Duck Bridge and Milltown Dam. Total metals concentrations used in this analysis were also based on the USGS total metals to TSS regression.

Estimated dissolved metals concentrations predicted by each of the above described methods are compared to the proposed Temporary Construction-related Water Quality Standards for Milltown Reservoir Remedial Actions.

The predicted peak dissolved metal concentrations for each calculation method are presented for predicted TSS concentrations under Scenario 4a in Table 5-2 and Figures 5-4 and 5-5. As identified by shading on Table 5-2, although dissolved concentration predictions are provided for each of the evaluated methods, the total:dissolved concentration regression using only USGS surface water quality data was primarily utilized for evaluating potential downstream risks because it provided the most conservative estimate of dissolved copper and was based on a consistent data set. Figure 5-6 shows predicted dissolved copper and arsenic concentrations plotted versus time over the course of the Scenario 4a estimated construction period, assuming the USGS regression method. The time plot suggests that elevated dissolved metals concentrations would generally be brief in duration, and elevated concentrations would be associated only with the initial high concentration sediment release pulses predicted after drawdown/dam breach implementation.

As illustrated by comparing Figure 5-6 against reservoir drawdown and flow routing stages for Scenario 4a shown on Figure 4-7, predicted dissolved copper concentrations were generally elevated during powerhouse routing and dam removal with the highest concentration (i.e., approximately 23 *u*g/L predicted to occur under the USGS regression method) immediately following dam removal. Dissolved copper concentrations rapidly declined to baseline levels of approximately 3 *u*g/L within a short time period after dam removal. For comparison, the maximum dissolved copper concentrations measured during the 1996 ice scour event below Milltown Dam were 11 *u*g/L (in the USGS data set) or 30 *u*g/L (in the Missoula County data set).

The proposed temporary standard for dissolved copper compliance is 25 *u*g/L and is based on a value equal to 80% of the hardness dependent acute trout TRV for dissolved copper on the CFR. HEC-6 modeling runs estimated that dissolved copper concentrations downstream of the dam would not exceed the compliance value of 25 *u*g/L under any correlation to predicted TSS concentration method used (Table 5-2).

Predicted dissolved arsenic concentrations showed similar elevated values immediately after powerhouse routing and dam removal periods, with a rapid decline to baseline values predicted. The predicted peak dissolved arsenic concentration of about 12 *u*g/L, estimated using the USGS data set regression equation, was slightly above the 10 *u*g/L drinking water standard, but concentrations above 10 *u*g/L were only predicted to occur for 3 days. Also the USGS data set regression may overestimate predicted dissolved arsenic concentrations given it was developed using surface water quality data collected when flow is in the existing CFR channel. Dissolved arsenic concentration baseline levels were estimated to be about 4 *u*g/L. For comparison, the maximum dissolved arsenic concentrations observed below Milltown Dam during the 1996 ice scour event were 9 *u*g/L (measured by USGS) or 13 *u*g/L (measured by Missoula County). No exceedances of either the 340 *u*g/L short-term (1 hour) or 10 *u*g/L long-term (30-day average) dissolved arsenic proposed temporary construction related water quality standards were predicted. Note that comparison to the 10 *u*g/L arsenic drinking water standard is limited to long-term conditions because the CFR surface water below Milltown Dan is not used for drinking water and any impact to groundwater arsenic concentrations from surface water recharge is considered to be of potential concern only if it occurs for an extended period.

5.4 Predicted downstream nutrient and BOD concentrations

5.4.1 Nutrients

There is no known data on nutrient levels that correspond to the peak TSS concentrations resulting from predicted Milltown Reservoir scour. Assuming that the relationships shown in Figures 5-7 and 5-8 apply at higher TSS concentrations, a first approximation of nutrient concentrations can be derived. The regression equations for the data presented in Figures 5-7 and 5-8 are as follows:

$$TN\ (mg/L) = 0.209 + (TSS * 0.004)$$

$$TP\ (mg/L) = 0.012 + (TSS * 0.001)$$

Using these relationships the following table shows some example nutrient concentrations:

Nutrient Concentrations vs. TSS

TSS (mg/L)	TN (mg/L)	TP (mg/L)
10	0.249	0.022
50	0.409	0.062
100	0.609	0.112

500	2.209	0.512
1000	4.209	1.012
2000	8.209	2.012

5.4.2 Biological Oxygen Demand

Biological oxygen demand (BOD) is not conventionally measured within the water column in northern climates due to the typically well-mixed and oxygenated character of rivers in those areas. Rather, dissolved oxygen is measured directly. BOD is commonly monitored in effluent from particular point sources like feed-lots, pulp mills, etc.

No useful BOD dataset was found that could be used for context or analysis to determine projected potential impacts from the scour of sediment from the Milltown Reservoir. However, five BOD samples were taken during the August 2002 drawdown at Milltown. The relationship between these data and TSS is shown in Figure 5-9. Interestingly, the highest BOD concentration (3.250 mg/L) was collected on the same day as the lowest (of the five sample days) TSS concentration (87 mg/L). This result in not statistically significant but may provide some indication that the BOD-TSS correlation is not necessarily positive or linear.

5.5 Potential Irrigation Impacts

There are forty-three legal water withdrawal points on the CFR between Milltown Dam and the BR confluence (Figure 5-10 and Appendix Table D-4). Of these, thirty-nine are listed as being pumps (whether or not these pump sites are actually in use on an annual basis is not known). The remaining four points are diversions for moderate-sized ditch companies or irrigation districts (Figure 5-11). From upstream to downstream these are:

- Missoula Irrigation District Diversion (Photo 1 on Figure 5-12)
- Orchard Homes Ditch Company Diversion (Photo 2 on Figure 5-12)
- Hellgate Irrigation District (Flynn-Lowney Ditch) (Photo 3 on Figure 5-12)
- Grass Valley – French Ditch (Photo 4 on Figure 5-12).

The Department of Natural Resources and Conservation uses a climatic area method to set the period of use for water rights. Using this method, the period of use for all of the water rights from the Dam to the BR was determined to be either year-round or limited to the April 15 to October 19 period (see Appendix Table D-4).

The maximum diverted flow rates for the four surface diversions in the evaluation area are shown in the following table:

Maximum Flow Rate for Surface Diversions on CFR

Diversion Name	**Maximum Flow Rate (cubic feet per second)**

Missoula Irrigation District	88.3
Orchard Homes Ditch Company	19.8
Hellgate Irrigation District	62.5
Grass Valley – French Ditch	105.8

5.5.1 Potential Irrigation-Related Issues

There are two potential categories of impacts to irrigation diversions from sediment released from Milltown Reservoir.

5.5.1.1 Hydraulic Modifications

Hydraulic modifications are defined as the effect that sediment would have on the ability of the irrigators to physically get their water right. Fine sediment could potentially aggrade at or near the inlet of the ditch or in the ditch itself, reducing the efficiency of the diversion. Similarly, the functionality of pump intakes could be reduced. However, given that the predicted downstream sediment concentrations associated with remedial activities at Milltown are generally within the levels seen historically during high flow and ice scour events, any impacts are likely to be at or below levels that have historically occurred. Also the drawdown stages assumed for Scenario 4a all occur in the winter/early spring and any sediment transport/downstream deposition effects related to each drawdown stage are predicted to be short-lived and not result in significant impacts during the irrigation season.

5.5.1.2 Metals Impacts

Water that is diverted or pumped from the CFR is likely to contain some level of metals at certain times. Given that dam removal modeling results do not predict metals levels significantly above what has been seen historically and because the periods of predicted higher metals concentrations occur outside the irrigation season, impacts from metals in diverted CFR water would not be expected. However, to address perceived concerns about potential metals impacts three potential mechanisms that could bring about detrimental impacts from metals in diverted water were individually evaluated. These mechanisms, which are outlined in the following paragraphs, are Livestock Watering, Domestic Use, and Irrigated Crops.

<u>Livestock Watering</u>
Following the CFR Ecological Risk Assessment (ERA) (ISSI 1999) cattle dose model and toxicity reference values, the concentration in surface water associated with a hazard quotient (HQ) of 1, where the dose equals the toxicity reference value (TRV), was calculated. The EPA model assumed a cattle body weight of 272 kg and a water ingestion rate of 41.5 liters/day. The body weight adjusted ingestion rate was 0.15 l/kg/day. For an HQ of 1 the TRV dose value equals the TRV in mg/kg-d. This value divided by the body weight adjusted ingestion rate in l/kg/d results in the concentration in water in mg/L equal to the HQ of 1.

The resulting no observed adverse effect level (NOAEL) water total concentrations for Arsenic, Cadmium, Copper, Lead and Zinc are 1.1, 0.4, 7.4, 0.4 and 11.1 mg/L respectively. The corresponding lowest observed adverse effect level (LOAEL) for Arsenic, Cadmium, Copper, Lead and Zinc are 1.7, 1.2, 22.2, 1.3 and 33.3 mg/L respectively.

The Milltown remediation project would have to result in downstream irrigation water concentrations greater than the NOAEL values before any potential risks are predicted from the surface water ingestion exposure pathway used in EPA's CFR ERA model. It is unlikely that total metal and arsenic concentrations will result in cattle exposures that exceed the NOAEL or LOAEL values reported here.

The EPA risk assessment assumed a large water ingestion rate of 41.5 liters/day (11.0 gallons/day) for cattle and 100% relative bioavailability (RBA) of total metals and arsenic. Studies suggest the RBA of 100% is highly conservative as only some fraction of total metals ingested is likely absorbed. To the extent cattle drink less than 41.5 liters/day of CFR water, the calculated NOAEL and LOAEL concentrations will be proportionally higher than reported by use of the EPA model assumptions. As the estimated metals exposure is less than the TRV related water concentration, risks to cattle from drinking water exposure are not predicted.

<u>Domestic Use</u>
No domestic use water rights were identified between Milltown Dam and BR, therefore this potential risk pathway would not be of concern during the Milltown remedial action.

<u>Irrigated Crops</u>
The impact of metals on vegetation have been studied in the Upper Clark Fork watershed. Irrigation with CFR water has been occurring for over 100 years. The Public Review Draft CFROU Feasibility Study (Pioneer Technical Services 2002) Appendix A5 concluded that the only impacts to crop productivity in the 14,600 acres of irrigated land, between Warm Springs Ponds and the Milltown Reservoir was a localized area below the East Valiton Ditch south of Deer Lodge. This ditch was known to have been used when the “river ran orange” with highly contaminated water that had low pH and elevated dissolved metals. Low pH and/or high dissolved metals concentrations downstream of the dam are not anticipated due to the relatively uncontaminated sediment that could be released into the CFR during a Milltown remedial action under the bypass channel scenario.

Furthermore, a study of a ranch near Garrison found no significant difference between a pasture irrigated with CFR water and one irrigated with water from a spring creek with no metals contamination (Pioneer Technical Services, 2002).

Regarding a potential concern of deposition of scoured sediments on irrigated field downstream, evaluations done by the EPA for the Clark Fork Risk Assessment identified that impact to vegetation would not be predicted in soils with near neutral pH unless metals concentrations were in the 1,000's or tens of 1,000's of mg/kg. As discussed in Section 5.1, metals concentrations in the scoured sediment are predicted to be in the 100's of mg/kg at most; therefore, metals concentrations from deposition of scoured sediment on irrigated fields should not be a concern.

Downstream Groundwater Quality Impacts Due to Deposited Sediment

The Continued Releases Risk Assessment (Environmental Toxicology International 1994) study predicted that deposition in the downstream floodplain would average 0.25 inches with possible localized depths up to 1 foot under the greater volume of sediment, with potentially higher average metals concentrations, that would be released under a dam failure scenario. This study concluded that deposition in floodplain areas would not result in impacts to shallow groundwater suggesting that downstream deposits of the lesser amount of sediments released during a Milltown remedial action should not present a concern from a groundwater quality standpoint.

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